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Shoulder kinetic during pitching in baseball players with scapular dyskinesis

Atsushi Ueda [a,*], Aoi Matsumura [b], Takafumi Shinkuma [c], Takeshi Oki [c], Yasuo Nakamura [d]

[a] Department of Rehabilitation Sciences, Faculty of Allied Health Sciences, Kansai University of Welfare Sciences, Japan
[b] TAKE PHYSICAL CONDITIONING Inc., Japan
[c] Department of Orthopaedic Surgery, Hankai Hospital, Japan
[d] Department of Health and Sports Science, Doshisha University, Japan

A R T I C L E I N F O

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A B S T R A C T

Introduction: Shoulder injuries in baseball players cause excessive shoulder load during pitching and scapular dyskinesis (SD). However, the characteristics of pitching kinetics in the shoulder joint with SD are unclear. This study aimed to investigate the effect of SD on pitching kinetics in the shoulder joint of baseball players.
Method: Seventy-two college and independent league baseball players participated in the study. The pitching motion was measured using an 18–camera motion-capture system. SD was classified into four types (I–IV) using the scapular dyskinesis test (SDT). The pitching kinetics data were analyzed.
Results: The agreement of SD in this study was 56/72 (77.8%). SD were classified into 31 abnormal group (type I–III) and 25 control group (type IV). Three participants with measurement failure during the pitching motion analysis were excluded from the analysis. The abnormal group showed a larger maximum value of the glenohumeral normalized anterior joint force than the control group.
Conclusions: These results suggest that an increase in GH anterior force during pitching causes an excessive increase in external rotation of the GH with an insufficient posterior tilt of the scapula with SD. Therefore, baseball pitching with SD may involve shoulder injuries owing to excessive shoulder load during pitching.

1. Introduction

Shoulder injuries in baseball players are common upper-extremity injuries (Burkhart et al., 2003c; Fares et al., 2020; Wasserman et al., 2019). Previous studies have reported that shoulder injury rates among all injuries in college and professional baseball players are the highest at 21% and 27%, respectively (Fares et al., 2020; Wasserman et al., 2019). Shoulder injuries in baseball players are a factor in pitching motion due to the large range of motion and high throwing velocity, which causes an increase in the mechanical stress placed on the shoulder joint (Burkhart et al., 2003a). Furthermore, repetitive throwing motions of overhead-throwing athletes with shoulder dysfunctions cause pathological alterations to the shoulder joint (Burkhart et al., 2003b). Therefore, to prevent shoulder injuries in baseball players, clinicians should consider the relationship between shoulder function and pitching biomechanics.

Shoulder biomechanics during the late cocking phase of the baseball pitching cause from 158° to 178° of shoulder external rotation (Aguinaldo and Chambers 2009; Fleisig et al., 2006; Nissen et al., 2007; Sabick et al., 2004) and an increase in the shoulder anterior force (Fleisig et al., 1995). As a result, an excessive shoulder external rotation and an increase in shoulder anterior joint force during pitching are associated with throwing-related shoulder injuries, such as superior labrum anterior to posterior (SLAP) lesions (Kuhn et al., 2003), anterior shoulder instability (Mihata et al., 2004), rotator cuff injury (Fleisig et al., 1995), and internal impingement (Mihata et al., 2012). Moreover, baseball players with abnormal scapular motion develop shoulder injuries due to excessive shoulder loading during pitching (Burkhart et al., 2003b).

Scapular dyskinesis (SD) is a primary factor in shoulder disorders (Kibler et al., 2013). Defined as an abnormal scapular static position and motion (Kibler et al., 2013), SD is classified into four types: type I, inferior prominence of the scapula; type II, medial border prominence of the scapula; type III, excessive scapular elevation and upward rotation; and type IV, normal scapular motion (without SD) (Kibler et al., 2002). In regards to SD and shoulder injuries, SD involves the development of

* Corresponding author. 3–11–1 Asahigaoka, Kashiwara–shi, Osaka-fu, 582–00026, Japan
E-mail address: at-ueda@tamateyama.ac.jp (A. Ueda).

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various shoulder injuries, such as rotator cuff injuries, subacromial impingement, glenohumeral (GH) joint instability (Burkhart et al., 2003b; Hickey et al., 2018). Regarding SD and abnormal scapular motion during shoulder movement, SD types I and II involve abnormal scapular motion with excessive scapular internal rotation and insufficient scapular posterior tilt (Huang et al., 2015; Park et al., 2013), respectively. Abnormal scapular motion can cause excessive shoulder motion and mechanical stress during the pitching motion (hyper angulation), resulting in pathological alterations of the shoulder joint (Burkhart et al., 2003b). However, there is a lack of evidence regarding the relationship between abnormal scapular motion and pitching biomechanics.

The current study found that SD type I (decreased scapular posterior tilt) increased external rotation of the glenohumeral joint (GH) and decreased posterior tilt of the scapulothoracic at the maximum shoulder external rotation (MER) during the pitching motion compared to a control group without SD (Ueda et al., 2021). As a result, we have mentioned that baseball players with SD may have experienced an increase in mechanical load on the shoulder joint, resulting in an increase in GH motion and a decrease in scapular motion during the pitching movement (Ueda et al., 2021). However, previous studies have not clarified whether SD is associated with shoulder load during the pitching motion. The relationship between SD with scapular malposition, abnormal motion, and shoulder load during the pitching motion may help in understanding the pathological mechanism of throwing-related shoulder injuries. Hence, the hypothesis was that baseball pitching with SD would increase shoulder loading during pitching motion. The current study aimed to investigate the characteristics of shoulder kinetics during baseball pitching in SD.

2. Methods

2.1. Participants

Participants in the kinetic analysis during a baseball pitching motion included 72 asymptomatic healthy baseball players (66 college baseball players and 6 baseball players in an independent league in Japan), including participants in our previous study (kinematic analysis) (Ueda et al., 2021). A power analysis was performed to determine the sample size using G*power (version 3.1.9.4, Kiel University, Germany). The sample size of our study was estimated to be 23 participants per group (Cohen's D > 0.8). The current study fulfilled the sample size requirement by adding five participants from the authors' previous study (Ueda et al., 2021) to analyze kinetic data during baseball pitching. Additionally, to be up to date the sample data in this study, all data were recalculated. Patients with shoulder pain during various shoulder motions during the last three months were excluded from our study. The current study was approved by the ethics committee of Doshisha University. All participants provided written informed consent.

Demographic data are shown in Table 1. Bilateral shoulder internal and external rotation range of motion (ROM) and maximum ball velocity during the pitching motion were also measured. Passive internal and external rotation at 90°abduction of the shoulder was measured using a goniometer (Awan et al., 2002). Differences in the shoulder internal range of motion between throwing and non-throwing sides were also calculated to assess glenohumeral internal rotation deficits (GIRD), then throwing and nonthrowing >15° was determined based on GIRD assessment (Maenhout et al., 2012). The maximum ball speed during pitching was measured using a radar gun (Ueda et al., 2021).

2.2. Scapular dyskinesis classification

SD was assessed using the scapular dyskinesis test (SDT) (Kawasaki et al., 2012; Kibler et al., 2002). The SDT method in this study was performed with bilateral shoulder flexion and abduction with 2–kg weights for three cycles using the measurement method described in previous studies (Ueda et al., 2021). Shoulder movement speed during the SDT was set at 3 s for raising and 3 s for lowering. Two physical therapists with >6 years of experience in musculoskeletal disorder rehabilitation assessed SD. Only those deemed to have SD by both physiotherapists were included in the study. Exclusion criteria comprised discrepancies in SD assessment between the physical therapists and those with shoulder joint symptoms during SDT. The evaluation criteria for SD are classified into types I–IV) (Kibler et al., 2002). Our participants were assigned to abnormal (SD types I−III) and control (normal; SD type IV) as described (Uhl et al., 2009).

2.3. Biomechanical analysis

Baseball pitching was measured using an 18–camera motion capture system (Mac3D; Motion Analysis, Rohnert Park, California, USA). Fifty–six reflective markers were affixed to the entire body. The pitching practice was conducted for approximately 10 min. The pitching task for all participants was performed as a straight throw on a flat floor (Ueda et al., 2021).

The scapular kinematics during baseball pitching was measured using the acromion marker cluster (AMC) method described in the author's previous studies (Matsumura et al., 2019; Ueda et al., 2021). Previous studies have reported that measurement of scapular motion during a pitching motion using a magnetic sensor, the intraclass correlation coefficient (ICC) (standard error of measurement: SEM) of the scapula angle during the pitching motion at the maximum shoulder external rotation and ball release periods were 0.91–0.85 (2.2–4.0°) and 0.89–0.93 (3.1–4.5°), respectively (Meyer et al., 2008).

The coordinate systems are the global coordinate system (ΣCa) and local coordinate systems of the thorax (ΣTh), scapula (ΣS), upper arm (ΣU), forearm (ΣFa), and hand (ΣH). The coordinate systems were referenced using the method described by the International Society of Biomechanics (Wu et al., 2005). In comparison to the author's previous study, kinematic parameters during the pitching motion were calculated for external (+)/internal (−) rotation of the thoracohumeral joint (ΣU relative to ΣTh: TH) and scapulohumeral joint (ΣU relative to ΣS: GH), and posterior (+)/anterior (−) tilt of the scapulothoracic joint (Σs relative to ΣTh: ST), respectively (Wu et al., 2005). To calculate each joint angle, rotational sequences proposed by the International Society of Biomechanics were used (Wu et al., 2005).

The joint force and moment during the pitching motion were calculated using an inverse dynamic analysis. The joint force and moment applied to the joints on the throwing side were calculated from the distal to proximal direction (from hand to shoulder) using the Newton-Euler method (Fleisig et al., 1995). Additionally, the joint force and moment in the shoulder joint were calculated as those of the TH and GH joints, respectively. With regard to the kinetic parameters, normalized data were also calculated using the values of body weight (kg) × gravitational acceleration (mg/s^2) for joint force and height (m) and body weight (kg) × gravitational acceleration (mg/s^2) for joint moment. The joint forces GH and TH were defined as anterior (+)/posterior (−), superior (+)/(−), and proximal (+)/distal (−), respectively. The joint moments of GH and TH were defined as horizontal abduction (+)/horizontal adduction (−) and external rotation (+)/internal rotation (−). The joint moments of GH and TH were defined as horizontal abduction (+)/horizontal adduction (−) and external rotation (+)/internal rotation (−).

2.4. Data analysis

A pitching trial of the fastest pitching was performed to analyze the data (Oliver & Weimar 2015). Pitching phases were defined as the stride foot contact (SFC), MER, and ball release (BR) periods (Ueda et al., 2021), respectively. The joint angles of the GH and TH were obtained for each period (SFC, MER, and BR). The maximum values of the ST angle, joint moment, and joint force were calculated using SFC and BR. The pitching cycle was normalized to 100% using SFC and BR. MATLAB R2020a (MathWorks, MA, USA) was used for analysis.

All statistical analyses were performed using IBM SPSS Statistics version 27 (IBM Corp., Armonk, NY, USA). Inter–rater reliability for SDT was assessed using the kappa coefficient. Demographic data, kinematics (joint angle), and kinetic parameters (joint force and moment) during baseball pitching between the abnormal and control groups were compared using independent sample *t*-tests to determine differences in demographic data, kinematics, and kinetic parameters. The significance level was set at 5%. Moreover, the effect size (Cohen's D) was calculated using G*power (version 3.1.9.4, Kiel University, Germany).

3. Results

Fig. 1 shows a flowchart of the recruitment process. The results of this study are presented in Table 1–4 and Fig. 2. The agreement of SD in this study was 56/72 (77.8%). The kappa coefficient for the inter–rater reliability of our SD assessment was 0.73.

The abnormal (SD type I) and control groups respectively comprised 28 and 25 of 56 participants. The abnormal group comprised 13, seven, four and four participants with isolated type I, types I + II, type I + III, and III, respectively. Twenty-four (42.8%), 7 (12.5%), and 8 (14.3%) of 56 participants had SD types I, II and III. None of the participants experienced pain during SDT or pitching motion measurements. Three participants in the abnormal group with missing markers or increased noise during the pitching motion analysis were excluded. We finally analyzed 53 (abnormal, n = 28; control, n = 25) participants.

There were no statistically significant differences in the demographic data of the participants between the two groups (Table 1). The incidence of GIRD in the abnormal and control groups was 15 and 16 participants, respectively.

Regarding the kinematic parameters of the GH during the pitching motion, the GH external rotation angle at the MER in the abnormal group was approximately 9° larger than that in the control group (p = 0.01, D = 0.75). There were no statistically significant differences in the other GH angles at the MER between the groups (Table 2). The maximum posterior tilt of the ST in the abnormal group from SFC and MER was approximately 6° smaller than that in the control group (p = 0.02, D = −0.70) (Table 2). Regarding the kinetic parameters of GH during the pitching motion, the abnormal group had a significantly larger maximum value (from SFC to MER) of normalized GH anterior joint force than the control group ($p < 0.01$; D = 0.74). There were no significant differences in other kinetic parameters (Table 4). The timing of the maximum value of the GH anterior force, ST posterior tilt angle, and GH external rotation angle were 46%, 63%, and 77% for the abnormal group, and 46%, 64%, and 77%, respectively, for the control group during the pitching cycle (Fig. 1) (see Table 3).

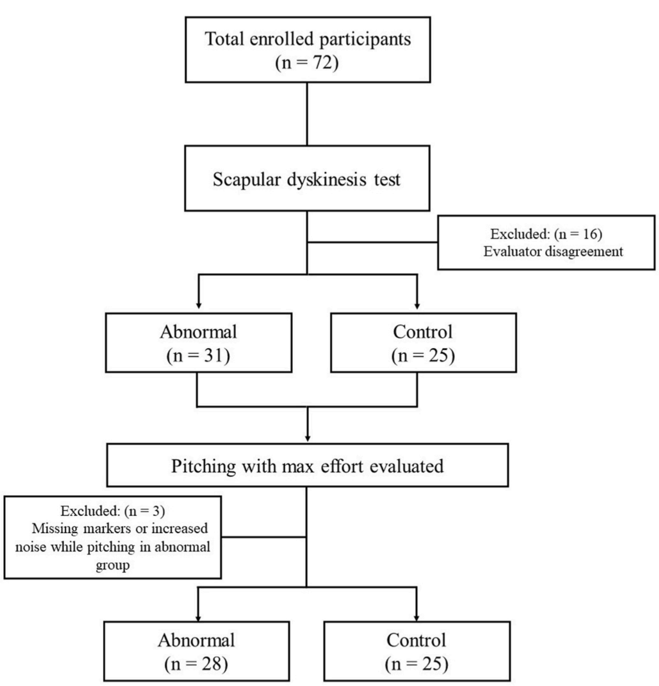

Fig. 1. The flowchart of the recruitment process.

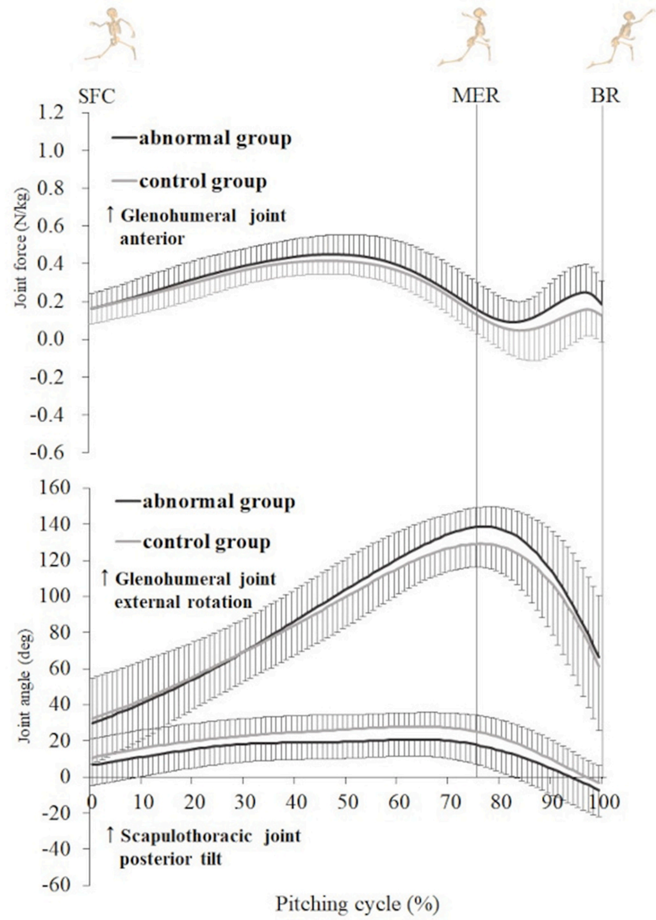

Fig. 2. Temporal changes in glenohumeral joint force (anterior/posterior force) and scapulothoracic and glenohumeral kinematics during baseball pitching in the abnormal and control groups (black line: abnormal group; gray line: control group). The pitching cycle during each period shows the average value between the scapular dyskinesis type (I -IV). Stride foot contact (SFC); maximum external rotation (MER); ball release (BR). Joint force; GH humeral orientation with respect to the scapula: anterior (+)/posterior (−). Joint angles; GH, glenohumeral joint: external rotation (+)/internal rotation (−). ST, scapulothoracic joint: posterior tilt (+)/anterior tilt (−).

4. Discussion

The current study aimed to clarify the kinetic alteration of the shoulder joint while players with SD pitched baseballs. The maximum GH anterior force from SFC to MER while pitching was significantly larger in the abnormal group than in the control group; Moreover, a GH external rotation at the MER was 9° higher and the maximum value of ST posterior tilt was decrease by 6° the abnormal group compared with the control group. These kinematic data obtained while pitching were similar to our previous findings (Ueda et al., 2021) and results partially supported our hypotheses.

Shoulder (TH) joint forces and moments during baseball pitching in

Table 1
Demographic data in the two groups.[a].

	Abnormal group (n = 28)	Control group (n = 25)	P value[b]	Effect size[c]
Age, years	20.5 ± 1.4	20.1 ± 1.4	.34	0.28
Height,cm	174.9 ± 5.6	175.6 ± 5.7	.69	0.12
Weight, kg	74.2 ± 7.4	75.3 ± 8.0	.79	0.14
Body mass index, kg/m2	24.2 ± 2.0	24.4 ± 1.7	.71	0.11
Competition history, years	12.4 ± 2.1	11.8 ± 2.7	.38	0.25
Shoulder internal rotation range of motion, deg				
Throwing side	32.2 ± 10.8	34.5 ± 12.6	.49	0.20
Non-throwing side	48.4 ± 12.3	51.5 ± 14.1	.42	0.23
Difference (throwing side - non-throwing side)	−15.6 ± 14.7	−17.0 ± 11.4	.73	0.11
Glenohumeral internal rotation deficit, nd	15	16		
Shoulder external rotation range of motion, deg				
Throwing side	109.8 ± 9.7	112.0 ± 9.7	.33	0.23
Non-throwing side	101.0 ± 7.8	100.2 ± 8.1	.81	0.06
Difference (throwing side - non-throwing side)	8.5 ± 8.8	11.8 ± 9.1	.17	0.10
ball velocity, m/s	31.2 ± 1.9	31.0 ± 2.3	.72	0.09

[a] Mean ± standard deviation.
[b] Values less than 0.05 were consided statistically significant.
[c] Cohen's d effect size.

Table 2
Shoulder joint kinematics during pitching in the two groups.[a].

Joint angle	Abnormal group (n = 28)	Control group (n = 25)	P value[b]	Effect size[c]
Maximum shoulder external rotation period				
Glenohumeral joint				
external rotation (+) /internal rotation (-), deg	140 ± 11	131 ± 13	.01	0.75
Humeralthoracic joint				
external rotation (+) /internal rotation (-), deg	160 ± 9	156 ± 9	.13	0.44
Maximum value				
Scaplothoracic joint				
posterior tilt (+) /anterior tilt (-), deg	25 ± 9	31 ± 8	.02	−0.70

[a] Mean ± standard deviation.
[b] Values less than 0.05 were consided statistically significant.
[c] Cohen's d effect size.

this study were smaller than those reported in previous studies (Fleisig et al., 1995; Oi et al., 2019; Pappas et al., 1985). The average values of body size (height and weight) and ball velocity in this study were lower than those reported in previous studies. Previous studies have reported that increases in the joint force and joint moment during pitching motion are associated with body size (height and weight) and ball velocity (Oi et al., 2019; Okoroha et al., 2018; Slowik et al., 2019). Therefore, the decrease in body size and ball velocity in our study may have reduced joint forces and moments during the pitching motion compared with previous studies. However, Oi et al. (2019) reported that the shoulder angle (external rotation and horizontal internal rotation) and angular velocity (internal rotation) during baseball pitching in Japanese individuals are greater than those in Americans, resulting in greater mechanical stress on the shoulder joint. Takagi et al. (2014) reported that an increase in the shoulder horizontal abduction angle at the MER during pitching motion is related to an increase in the shoulder anterior force. The findings of these previous studies suggest that an increase in shoulder joint load during the pitching motion is associated not only with body size and ball velocity, but also with an increase in shoulder motion during the pitching movement (Oi et al., 2019).

Table 3
Shoulder joint kinetics during pitching in the two groups.[a].

Kinetic parameters	Abnormal group (n = 28)	Control group (n = 25)	P value[b]	Effect size[c]
Maximum joint force				
Glenohumeral joint				
anterior (+) /posterior (-), N	361 ± 69	324 ± 64	.06	0.56
superior (+) /inferior (-), N	168 ± 66	152 ± 64	.39	0.25
proximal (+) /distal (-), N	640 ± 141	658 ± 184	.68	0.11
Humeralthoracic joint				
anterior (+) /posterior (-), N	342 ± 70	322 ± 73	.32	0.28
superior (+) /inferior (-), N	174 ± 50	169 ± 54	.73	0.10
proximal (+) /distal (-), N	628 ± 148	635 ± 168	.88	0.04
Maximum joint moment				
Glenohumeral joint				
horizontal abduction (+) /horizontal adduction (-), N/m	81 ± 19	78 ± 16	.55	0.17
external rotation (+) /internal rotation (-), N/m	−39 ± 11	−40 ± 14	.85	0.08
Humeralthoracic joint				
horizontal abduction (+) /horizontal adduction (-), N/m	63 ± 14	63 ± 14	.86	0.00
external rotation (+) /internal rotation (-), N/m	−63 ± 17	−60 ± 16	.48	−0.18

[a] Mean ± standard deviation.
[b] Values less than 0.05 were consided statistically significant.
[c] Cohen's d effect size.

The maximum normalized GH anterior force and GH external rotation at the MER was increased, and the ST posterior tilt peak was decreased while pitching in the abnormal, compared with the control group. This finding suggested that the incidence of SD type I with a decreased posterior scapular tilt was the highest among SD types in the abnormal group and that this caused kinetic changes while pitching. Fleisig et al. (1995) reported that the shoulder anterior force (TH joint) at the MER during pitching motion produced approximately 310 N (approximately 3 kg). An increase in shoulder anterior force during the pitching motion is caused by a variety of throwing-related shoulder injuries (Burkhart et al., 2003b; Fleisig et al., 1995; Takagi et al., 2014) due to increased anterior translation of the humeral head during pitching. Previous studies using cadavers have reported that maximum shoulder external rotation with an insufficient scapular posterior tilt increases the anterior shear force in the GH joint (Mueller et al., 2013). Therefore, researchers in previous studies have described that SD with scapular malposition and abnormal motion, such as a decreased posterior tilt (SD type I) are associated with the development of various shoulder injuries, such as anterior shoulder instability, rotator cuff disease, and SLAP lesions (Burkhart et al., 2003b; Fu et al., 2020). The

Table 4
Normalized data of shoulder joint kinetics during pitching in the two groups.[a]

Kinetic parameters	Abnormal group (n = 28)	Control group (n = 25)	P value[b]	Effect size[c]
Maximum joint force				
Glenohumeral joint				
anterior (+) /posterior (-) , N/kg	0.50 ± 0.09	0.44 ± 0.07	<.01	0.74
superior (+) /inferior (-) , N/kg	0.23 ± 0.12	0.20 ± 0.08	.26	0.35
proximal (+) /distal (-) , N/kg	0.88 ± 0.17	0.88 ± 0.20	.87	0.00
Humeralthoracic joint				
anterior (+) /posterior (-) , N/kg	0.47 ± 0.08	0.43 ± 0.08	.12	0.50
superior (+) /inferior (-) , N/kg	0.24 ± 0.07	0.23 ± 0.06	.47	0.15
proximal (+) /distal (-) , N/kg	0.86 ± 0.19	0.85 ± 0.18	.87	0.05
Maximum joint moment				
Glenohumeral joint				
horizontal abduction (+) /horizontal adduction (-) , N/m/height × kg	0.063 ± 0.011	0.060 ± 0.008	.26	0.31
external rotation (+) /internal rotation (-) , N/m/height × kg	−0.031 ± 0.007	−0.033 ± 0.009	.95	0.25
Humeralthoracic joint				
horizontal abduction (+) /horizontal adduction (-) , N/m/height × kg	0.050 ± 0.009	0.048 ± 0.008	.52	0.23
external rotation (+) /internal rotation (-) , N/m/height × kg	−0.049 ± 0.009	−0.046 ± 0.009	.21	0.33

[a] Mean ± standard deviation.
[b] Values less than 0.05 were consided statistically significant.
[c] Cohen's d effect size.

findings of the present and previous studies have suggested that an excessive increase in GH external rotation with reduced scapular posterior tilt while pitching in baseball players with SD can increase the GH anterior shear force at the MER during the pitching motion (Ueda et al., 2021).

Our results suggested that a simple assessment using the SDT can indirectly judge increased anterior shear force with excessive the GH external rotation during pitching. The current findings suggested that decreasing the GH anterior force during pitching baseballs is crucial for suppressing excessive external rotation with a sufficient posterior tilt of the scapula is also important for SD (Ueda et al., 2021). As a result, clinicians should fully consider training programs for baseball players with SD. Hence, our findings should provide fundamental knowledge that will help to prevent shoulder injuries and rehabilitation for overhead athletes with SD.

There were several limitations to the current study. First, there may be scapular motion measurement errors due to skin motion artifact of AMC on the scapula and other marker during the dynamic pitching motion (Oliver & Weimar 2015; Ueda et al., 2021). Second, the kinetic parameters (joint force and moment) of the GH and TH joints in this study were the resultant force and moment, whereas the contribution of each of the factors generating forces, such as various muscle contractions and extension of the ligament and joint capsule, could not be separately evaluated (Takagi et al., 2014). Third, the results of this cross-sectional study could not clarify the relationship between kinetic alterations, SD, and shoulder injuries. In the future, clarifying the longitudinal relationship between SD and shoulder injuries in baseball players is needed. We could not control the influence of GIRD on scapular static position and kinematic changes (Ellenbecker and Cools 2010; Thomas et al., 2010). Compared with the non-throwing side, GIRD in the throwing side (abnormal *vs*. control) was 15.6° ± 14.7° *vs*. 17.0° ± 11.4° all baseball pitchers studies had less than average glenohumeral internal rotation deficits (<10° ± 2°) (Borsa et al., 2008). Therefore, we inferred that our kinematic data were obtained with GIRD. We did not generalize baseball pitchers with below average glenohumeral internal rotation deficits (GIRD) (<10° ± 2°). Therefore, future studies will require biomechanical analyses to control the influence of GIRD.

5. Conclusions

The current study aimed to clarify the characteristics of shoulder load during baseball pitching with SD type I. Results showed that the maximum GH anterior force during the baseball pitching late cocking phase (from SFC to MER) in the abnormal group (SD type I) was significantly larger than that in the control group. These results suggest that an increase in GH anterior shear force during pitching due to excessive GH external rotation with insufficient ST posterior tilt motion with SD may cause shoulder injuries.

Clinical relevance

- A simple assessment using the scapular dyskinesis test can predict increases in anterior shear forces at the glenohumeral joint during pitching.
- To minimize shoulder load during pitching, clinicians should consider the scapular exercise program for scapular dyskinesis.
- Our findings provide a basis for understanding occurrence mechanisms of shoulder injuries with overhead athletes.

CRediT authorship contribution statement

Atsushi Ueda: Conceptualization, Data curation, Formal analysis, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. **Aoi Matsumura:** Methodology. **Takafumi Shinkuma:** Validation, Visualization. **Takeshi Oki:** Validation, Writing – review & editing. **Yasuo Nakamura:** Resources, Software, Supervision.

Declaration of competing interest

There is no know conflict of interest associated with this paper.

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